TYNDP 2026 Identification of System Needs Methodology Report

Public Webinar – Stakeholders Consultation

27 March 2026

ENTSO-E | System Development

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Reliable Sustainable Connected

Webinar Agenda

01	**Introduction & Context**	Zdeněk Hruška Francesco Celozzi	10 min
02	**Objectives & Key Assumptions**	Franck Dia Wagoum	15 min
03	**Input Data & Investment Candidates**	Kevin Knosala	15 min + Q&A
04	**Zonal Modelling & Data Preparation**	Patrick Freitag Lucas Lorenzo	15 min + Q&A
05	**Investment Modelling Framework**	Andriy Vovk	15 min + Q&A
06	**Consideration of Internal Constraints**	Mathilde Ceripa	10 min + Q&A
07	**Conclusion & Next Steps**	Franck Dia Wagoum	5 min

Housekeeping Rules

Interactive Discussion

This webinar is meant to be an interactive exchange with stakeholders

Ask Questions

Use the Q&A functionality to ask questions or raise your hand at the end of each section presentation

Recording

This meeting is recorded — recording and slides will be shared after the webinar

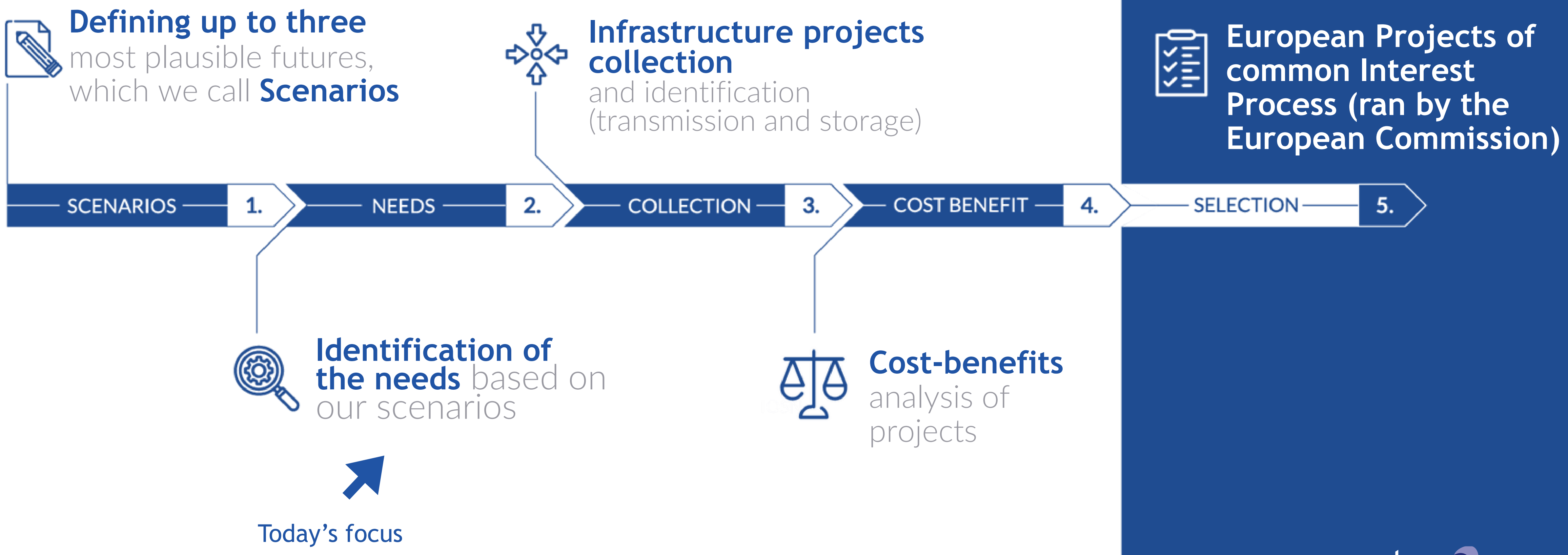
Public Consultation

Feedback can also be submitted via the public consultation platform

1. Introduction & Context

Zdeněk Hruška

ENTSO-E Planning tool:
The Ten-Year Network Development Plan (TYNDP)



2030
System Needs

With further investment in its electricity grid and storage infrastructure, Europe could reduce its system costs while going beyond its 2030 targets.

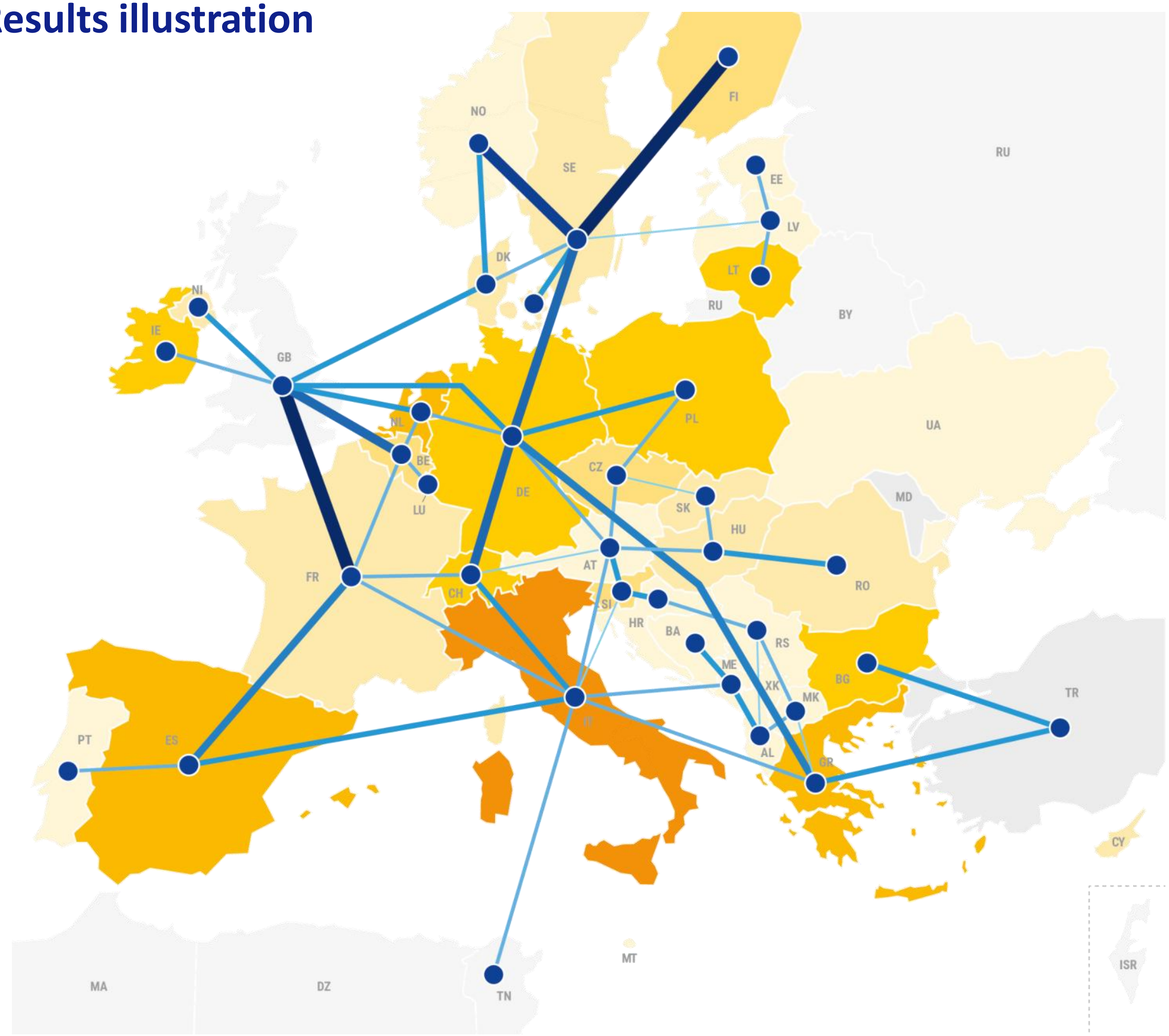
An additional 88 GW of complementary cross-border capacity and 56 GW of storage power would be cost-efficient to reinforce Europe's power system.

Cross-border capacity increases in 2030 (additional to 2030 starting grid)

- 1 – 500 MW
- 501 – 1,000 MW
- 1,001 – 2,000 MW
- 2,001 – 3,000 MW
- 3,001 – 4,000 MW
- 4,001 – 5,000 MW
- > 5,000 MW

Storage capacities per country in 2030

- 0 – 100 MW
- 101 – 500 MW
- 501 – 1,000 MW
- 1,001 – 5,000 MW
- 5,001 – 10,000 MW
- 10,001 – 20,000 MW
- > 20,000 MW



TYNDP 2024 Identification of System Needs Results illustration

2040 System Needs

By 2040 108 GW of additional cross-border capacity increases additional to the 2030 grid , including 20 GW of offshore hybrid corridors, would minimise the total costs of Europe’s electricity system.

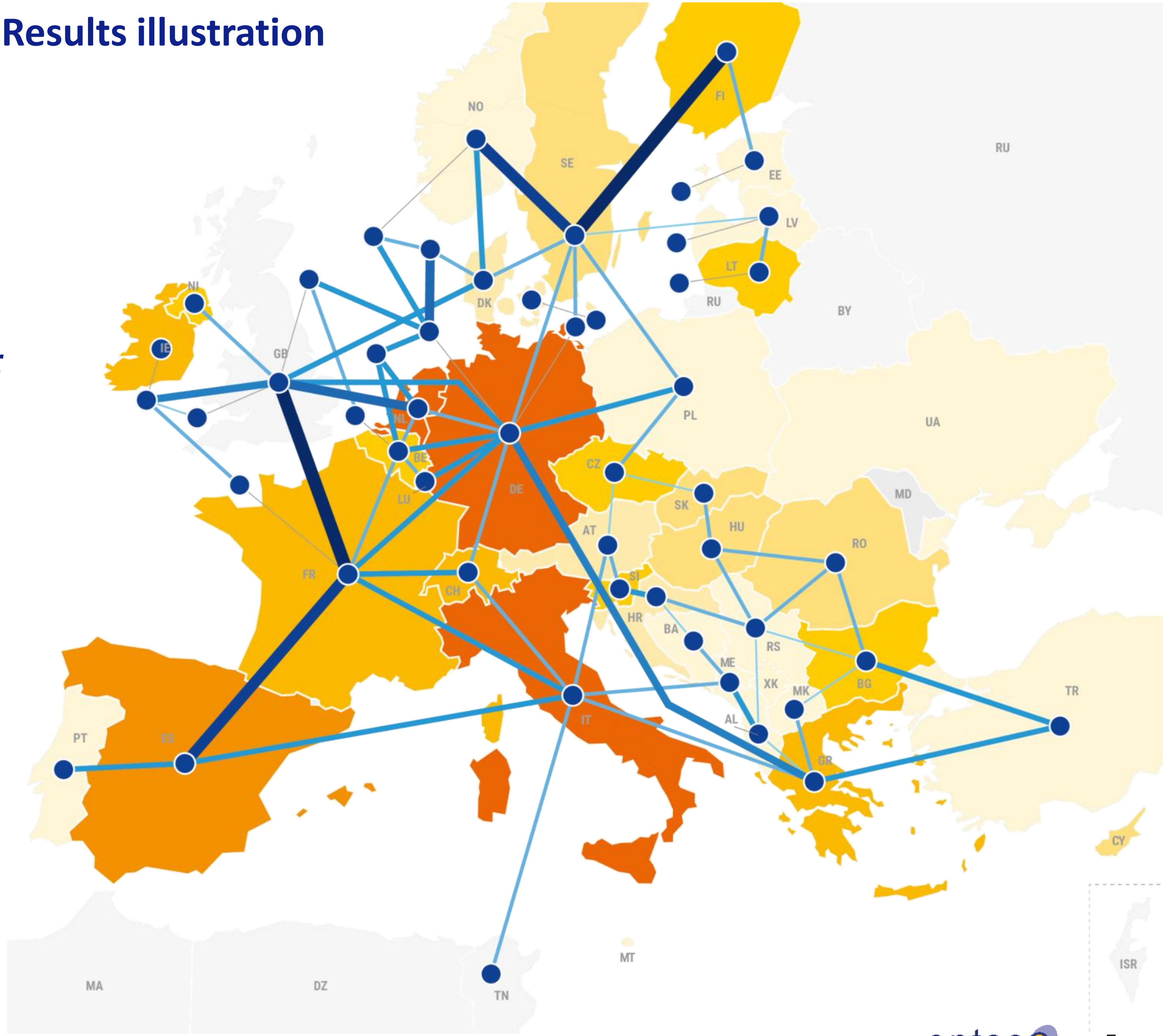
Each euro invested in the electricity grid translates into over 2 euros saved in system costs.

Cross-border capacity increases in 2040 (additional to 2040 starting grid)

- Home Market
- 1 – 500 MW
- 501 – 1,000 MW
- 1,001 – 2,000 MW
- 2,001 – 3,000 MW
- 3,001 – 4,000 MW
- 4,001 – 5,000 MW
- >5,000 MW

Storage capacities per country in 2040

- 0 – 100 MW
- 101 – 500 MW
- 501 – 1,000 MW
- 1,001 – 5,000 MW
- 5,001 – 10,000 MW
- 10,001 – 20,000 MW
- > 20,000 MW



2. Objectives of the Study & Key Assumptions

Franck Dia Wagoum

Overarching Goals of the IoSN

Cross-Border Transmission Needs

Provide a coordinated and transparent assessment of cross-border transmission capacity needs and offshore corridor needs across three target horizons

System Configurations & Expansion Opportunities

Inform stakeholders about potential system configurations and expansion possibilities that facilitate RES integration, sector coupling, market integration and system security, at minimum system cost

Support to National Development Plans

TYNDP as a coordination mean for TSOs to make NDPs. Inform TSOs and stakeholders about the potential impact of cross-border infrastructure developments and offshore network development on internal national electricity networks

Specific Technical Objectives

Strategic Opportunities

- Onshore cross-border capacity needs
- Storage capacity needs at transmission level (2040, 2050)
- Offshore hybrid corridors
- Impact on internal networks

Structural Modelling Enhancements

- Full zonal model (102 zones onshore)
- Robust optimisation across 3 weather scenarios
- Detailed offshore nodes representation

Integrated Assessment

- Unified onshore/offshore framework
- Alignment with Member States offshore targets
- Consistent with ONDP process

Sector Coupling

- Explicit hydrogen system modelling with electrolysers, H_2 storage, H_2 pipelines
- Co-optimised electricity & hydrogen dispatch with expansion on the electricity system

Model Topology & Key Assumptions

Electricity Sector

- Zonal representation
- Generation: RES, thermal, nuclear, hydro
- Flexible & inflexible demand
- Storage: batteries, pumped hydro
- Zones connected via AC/DC lines (Kirchhoff / DC load flow)

Hydrogen Sector

- Hydrogen zones connected via pipelines
- Electrolysers couple electricity and H_2 systems
- Hydrogen storage and demand
- Co-optimised dispatch alongside electricity
- Sensitivity: frozen H_2 dispatch to test electricity system – only assessment

Key Assumptions

- Target years: 2035, 2040, 2050 (2030 excluded – too close to reference year)
- Starting grid: 2035 cross-border grid (existing + planned TYNDP projects under construction / EIA completed / permitting)
- Geographical scope: full ENTSO-E area + third countries; investments limited to ENTSO-E (incl. observers) + UK area

Target Years & Starting Grid

2035	2040	2050
Short-term horizon	Priority planning horizon	Long-term vision

Starting Grid Definition (2035)

- Existing cross-border capacities in 2035
- TSO grid projects planned to be operational by 2035 affecting cross-border capacities
- TYNDP 2026 projects satisfying reference grid criteria:

a Under construction

b EIA completed

c In permitting / planned (timely realisation likely)

Note: 2040 is the priority horizon. Network reduction performed on the 2040 scenario model with 2035 grid at borders.

Offshore System Assumptions

- Offshore starting grid and installed generation capacities defined via top-down approach from Member States non-binding offshore RES targets
- Aligned with ONDP infrastructure assumptions and 2025 updated Member States targets
- Environmental protection and Maritime Spatial Plans (MSP) considered through a factor for re-routing and extra cost
- TSOs collected investment candidates, derived from TYNDP portfolio
- Theoretical offshore candidates defined centrally by ENTSO-E for connecting offshore nodes or creating hybrid corridors

Transmission Technology Selection

	≤ 1 GW	≤ 2 GW	> 2 GW
≤ 50 km	HVAC	Single HVDC	Multi-HVDC
> 50 km	Single HVDC	Single HVDC	Multi-HVDC

Standardised Cost Assumptions

- Based on Danish Energy Agency catalogues
- +15% cable routing factor for obstacles
- +30 km onshore connection standard
- HVDC 2GW 525kV with VSC

3. Input Data & Investment Candidates

Kevin Knosala

Input Data: Market & Network Datasets

PEMMDB – Market Data

- Thermal generation: capacity, heat rates, outage rates, must-run, derating factors
- RES capacities: wind, solar, run-of-river (linked to PECD profiles)
- Storage: batteries, pumped hydro (MW, MWh, efficiency)
- Demand-side response (DSR): flexible demand potential
- Power-to-X: electrolyser capacities and constraints
- Costs: fuel, CO_2, start-up, VO&M
- Fixed imports/exports

Network & Climate Data

- Grid topology: pan-European merged grid model (lines, substations, converters, transformers)
  - Zonal clustering from network reduction
- PECD v4.2: 42 historical + 153 projected weather years from 3 CMIP6 models (SSP2-4.5)
  - Wind/solar hourly profiles, temperature-dependent demand
  - Hydropower DB: 5 categories (RoR, pondage, reservoir, open/closed-loop PSP)
  - Demand Forecasting Toolbox (DFT): hourly load profiles incl. EVs, heat pumps

All data provided for each target year (2035, 2040, 2050), mapped to spatial and temporal resolution of the expansion model.

Investment Candidates Definition

Real Candidates

Concrete projects submitted by promoters for TYNDP 2026 CBA. Include CAPEX, OPEX, capacity, landing points.

Conceptual Candidates

Proposed by TSO-promoters to explore further system needs on top of real candidates. Same data requirements.

Theoretical Offshore

Defined centrally by ENTSO-E for connecting offshore nodes or creating hybrid corridors. Standardised cost assumptions.

Storage Candidates

- Standard capacities, power, and costs centrally defined by ENTSO-E for all countries
- Two types are envisaged: long duration and short duration storages.
- Expanded only for 2040 and 2050 time horizons
- Maximum expansion constrained by TSO-defined trajectories to avoid unrealistic levels (trajectories from TYNDP 2024 Scenarios)

Note: All transmission candidates (AC or DC) are modelled as DC links in the zonal model.

Economic Parameters

WACC	Weighted average cost of capital — reflects financing cost; used with Economic Life to annualise investment costs – **4% considered**
Discount Rate	Discounts future costs and benefits back to 2026 (the TYNDP study year) - **4% considered**
Economic Life	Period over which fixed costs are recovered — **25 years considered**
Build Cost (CAPEX)	Fixed investment cost, collected from project promoters during candidates' data collection and defined internally for theoretical candidates
FO&M Charges	Annual fixed operations and maintenance cost during asset lifetime
VoLL	Value of Lost Load — economic cost of unserved energy, used to penalise load shedding in optimization – **3000 €/MWh used throughout the TYNDP**

Q & A

Input Data & Investment Candidates

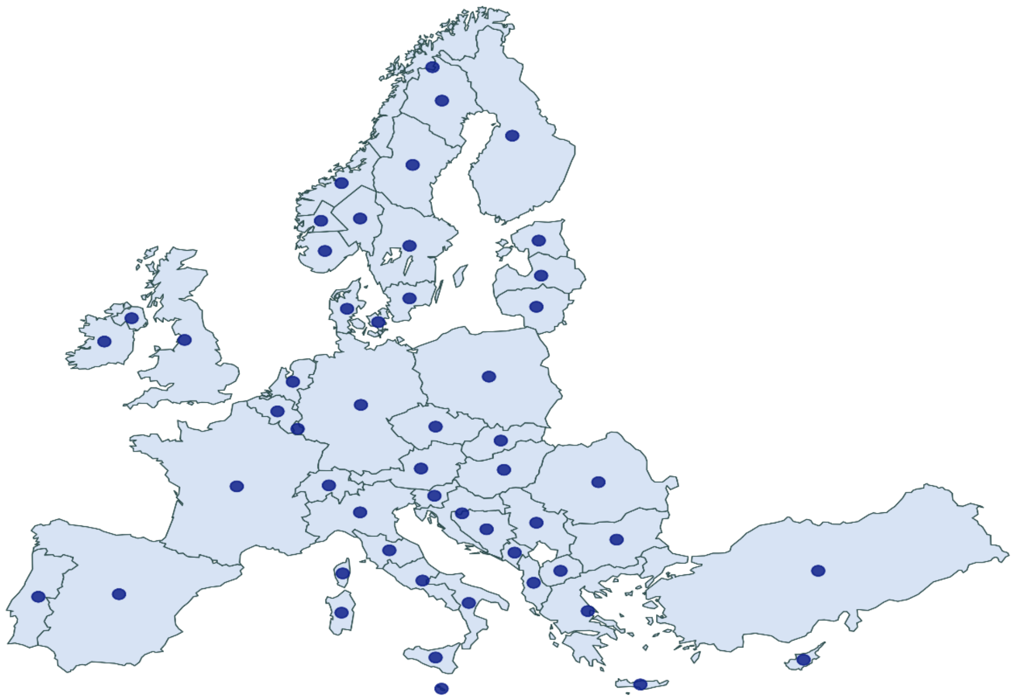
4. Zonal Modelling & Data Split Preparation

Patrick Freitag (Network reduction & clustering) | Lucas Lorenzo(Data split)

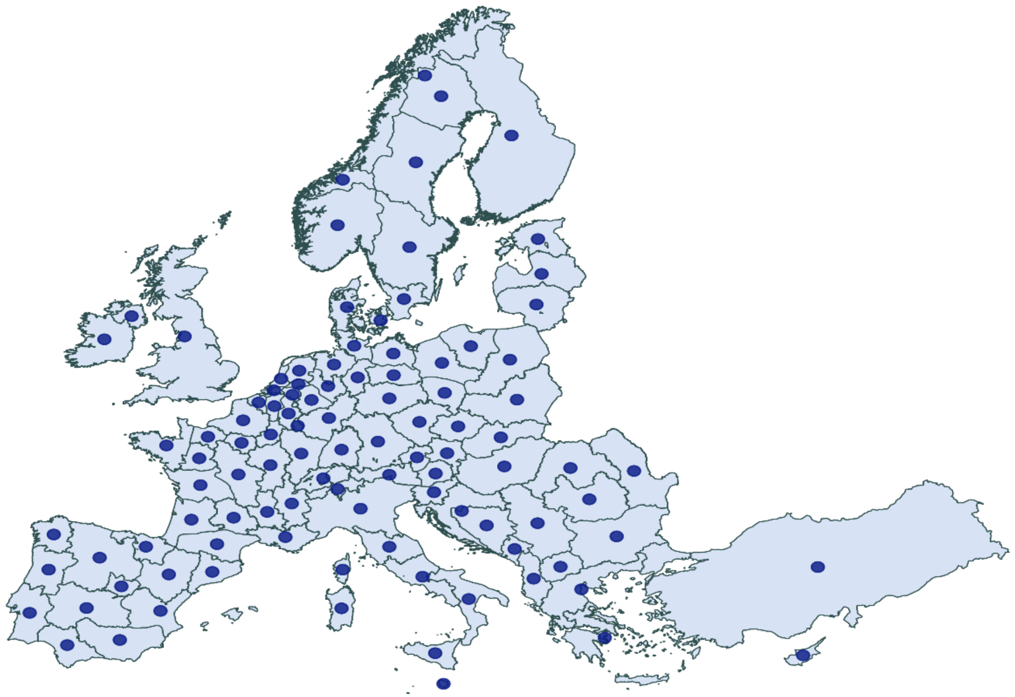
Spatial Resolution of the IoSN

Usually, the TYNDP processes are models on bidding zone level. In the IoSN these markets are further divided to consider internal bottlenecks and regional constraints

European Bidding Zones



Zonal Resolution (102 Region + Offshore*)



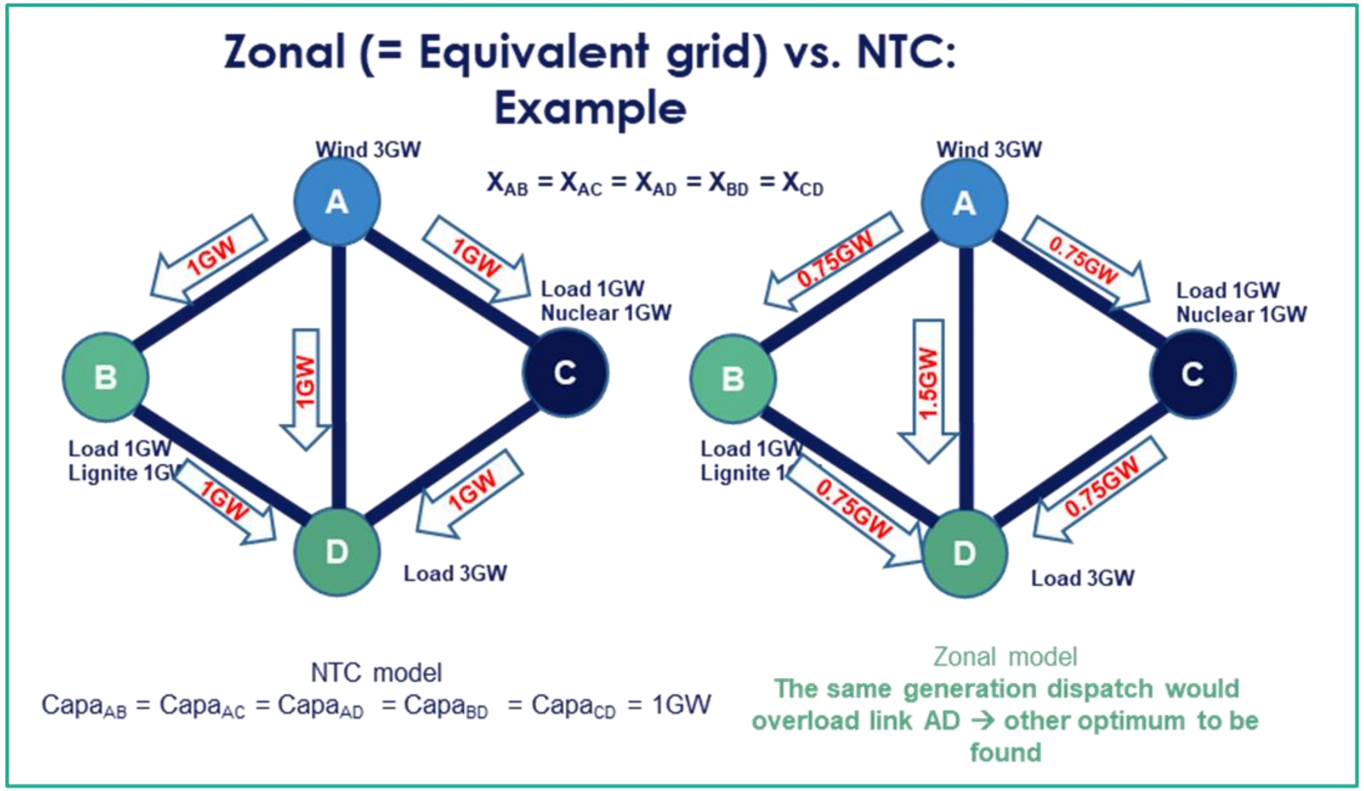
Process Steps for Modeling: Market split for distribution of loads and power plants to the respective zone, Power grid reduction for fitting the European grid to the resolution of the zonal model

** Offshore regions in the zonal model are explicitly modeled*

NTC vs. Zonal Model (Methodology)

The zonal model replaces the traditional one-node-per-country approach, better reflecting physical power flows by integrating a simplified model of the physical grid into the market model.

	NTC Model	Zonal Model (TYNDP 2026)
Nodes	1 per bidding zone	N per country (102 total)
Links	Cross-border only	Cross-border & internal
Binding constraints	None / specific	Kirchhoff's mesh rules
Results	Copper plates + HVDC links	Copper plates + AC grid (Physical Flow-Constraints)
Flow accuracy	Low (−)	High (+)



Key advantage: Zonal model captures internal bottlenecks and regional constraints, enabling identification of system needs with better awareness of grid limitations compared to NTC.

NTC vs. Zonal Model (Methodology)

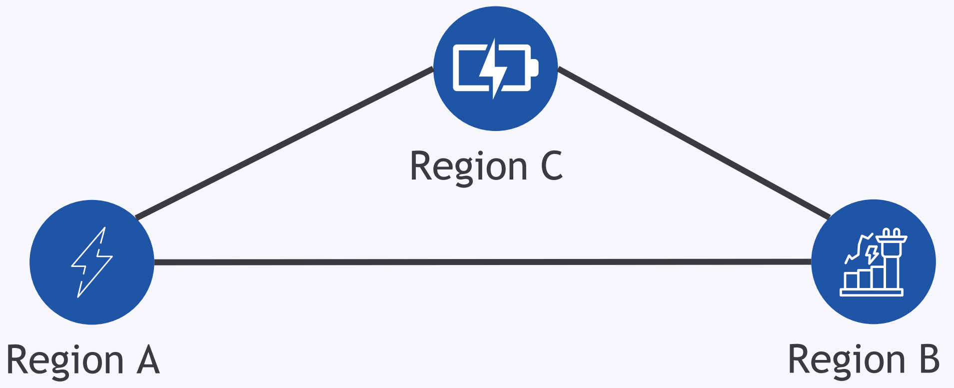
In the zonal model the power flow is also constrained by the Kirchoff's law for electricity flow. This we consider mesh rules for the modeled electricity grid.

NTC-Constrains

$$P_{X-Y} = P_t \qquad \forall\, t \in T, \forall\, Lines$$

$$P_t \leq P_{max}$$

$$P_t \in \Re$$

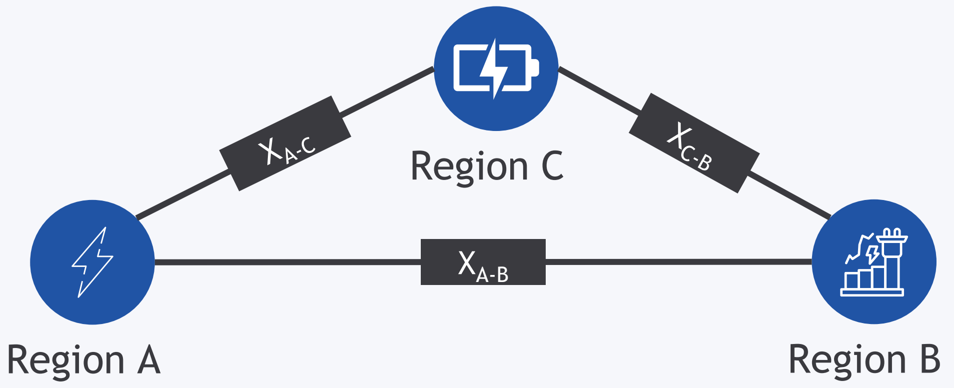


Zonal-Constrains (Flow Constraints)

$$P_{X-Y} = \frac{1}{x_{X-Y}}\left(\Theta_{X,t} - \Theta_{Y,t}\right) \quad \forall\, t \in T, \forall\, Lines$$

$$P_{X-Y} \leq P_{max}$$

$$\Theta_t \in \Re$$



Downside: The model including flow constraints is more complex compared to a conventional NTC consideration.

* $P_{X\text{-}Y}$: *Flow between Regions X and Y,* Θ_X: *Voltage angle at node X*

Zonal Clustering Criteria

1

Constrained lines on inter-zones

Critical and sensitive lines remain as monitored inter-zone connections. Ensures dispatch can be influenced by these key links.

2

Quality of equivalent network

Lines with similar impedance grouped on same inter-zone connection. Good approximation of physical flows.

3

Limit number of zones

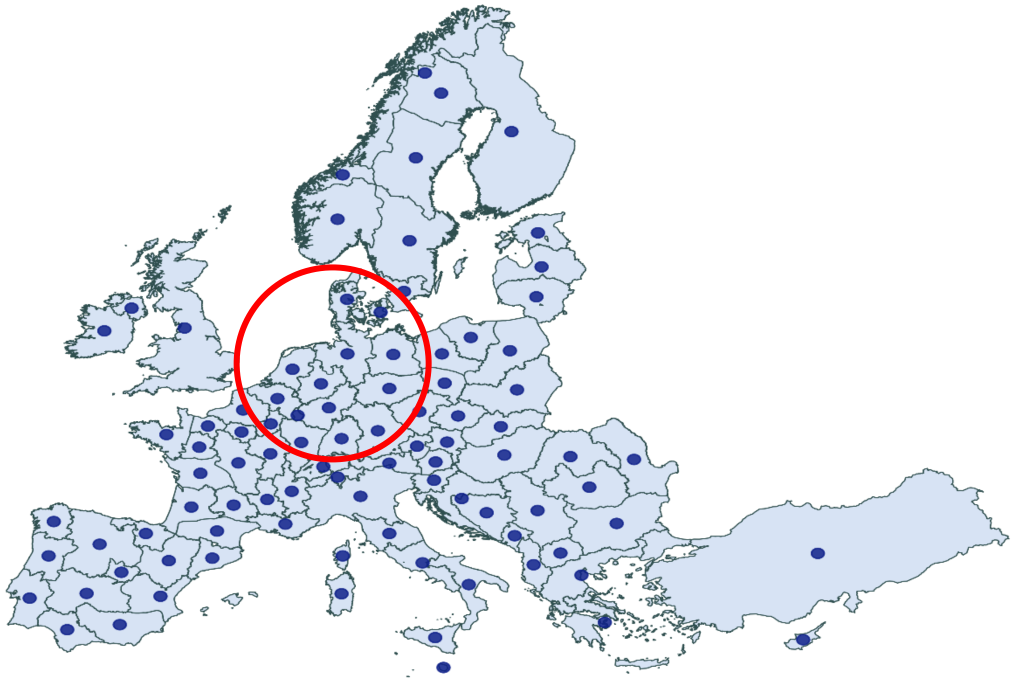
Balance between accuracy and computational feasibility. ~102 zones across Europe established as reliable target.

Additional considerations: good relative proportion between zones, no isolated parts within a zone, consistency with PECD zones for market data split.

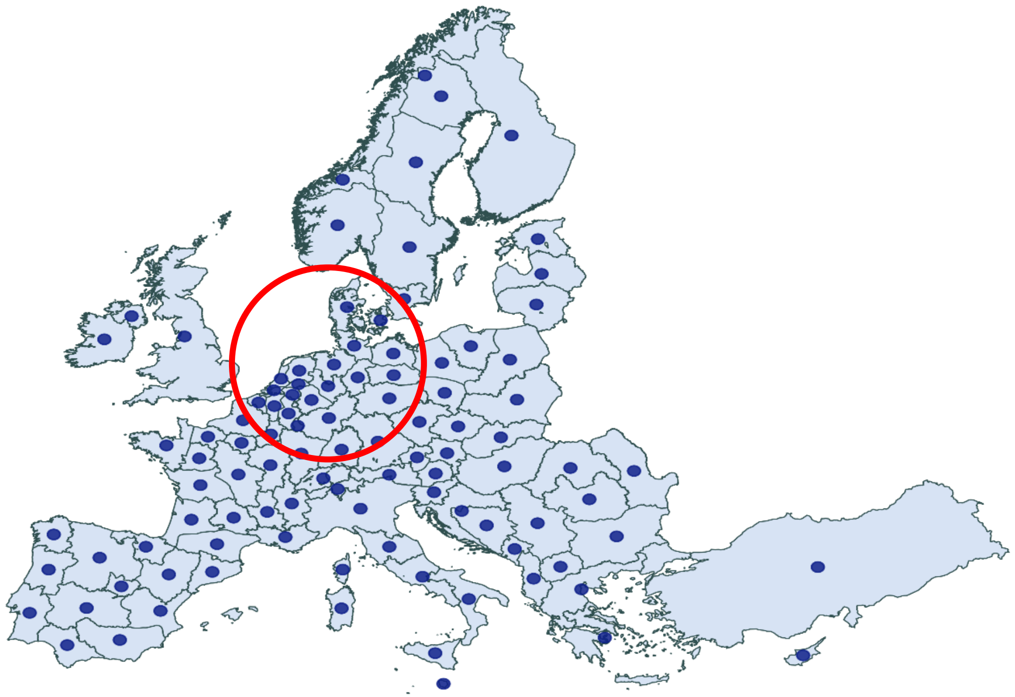
Development of the Zonal Clustering

Originally the zonal resolution of the IoSN was on PECD-Level. But this resolution led to a high error in the network reduction process.

Zonal Resolution (Original)



Zonal Resolution (now)



In an iterative approach the number zones was increased fit to decrease the error value of the network reduction process. Most notable the increase of zones in BENELUX and Germany.

Network Reduction Process

From thousands of nodes in the detailed grid to ~102 equivalent zones with preserved electrical characteristics.

Equivalent Impedances

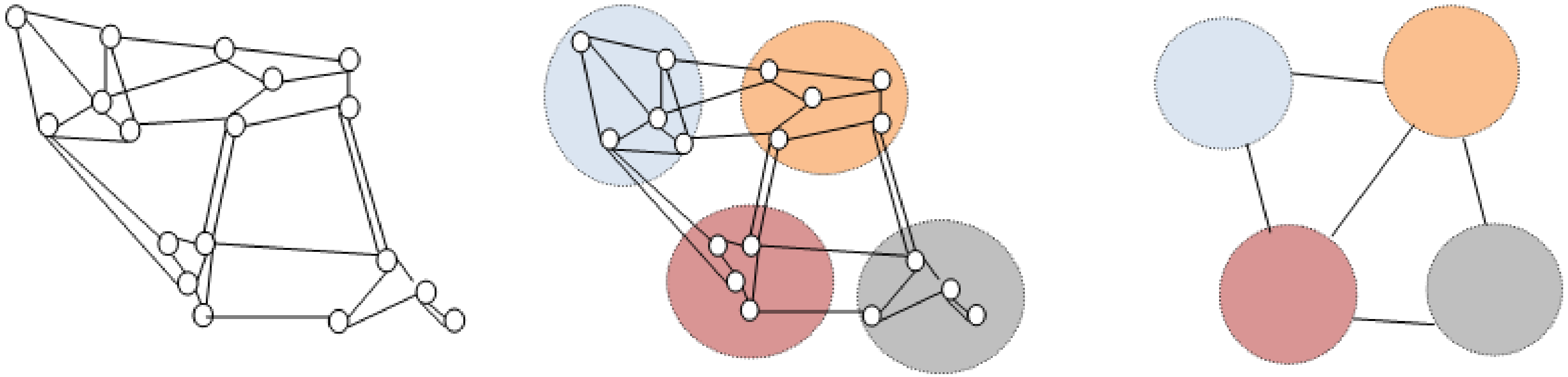
Optimisation determines impedances and flow corrections minimising error between estimated and reference DC load flows from a sample of physical flow snapshots. HVDC set to 0, PSTs to neutral tap for robustness.

Equivalent Capacities

N-1 secure transfer capacity for each inter-zone connection. Scatter-plot method: capacity = flow at 100% highest line loading. Summer/winter and directional values provided.

Iterative Quality Improvement

RMSE indicator used to evaluate reduction quality. Process: identify gaps → update clustering → test → assess indicators. Equivalent capacity quality also monitored.

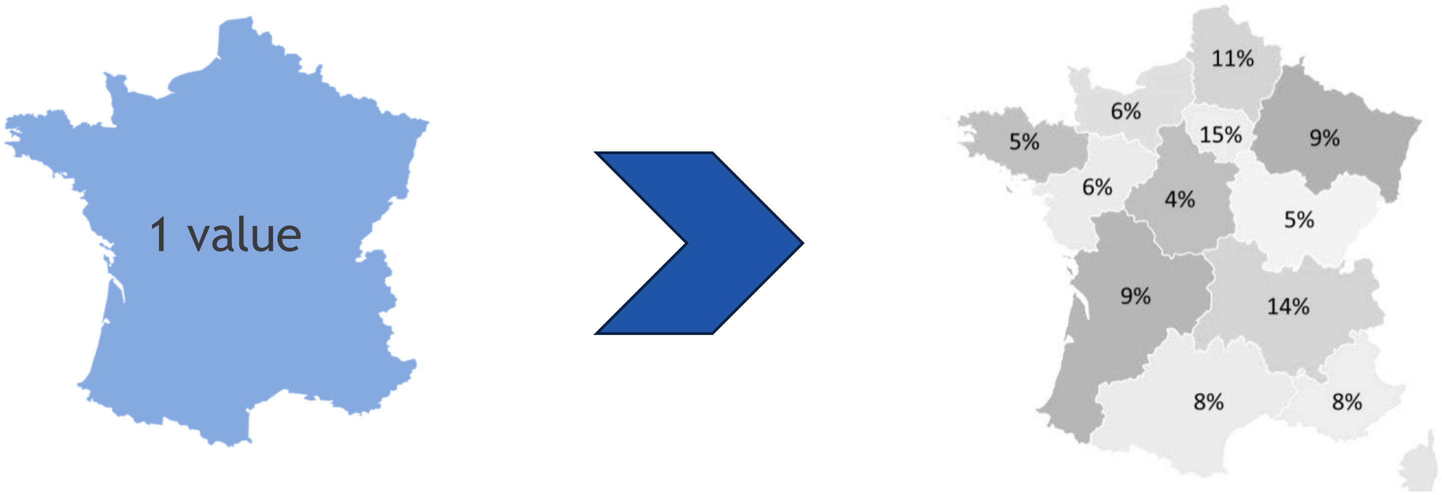


Key outputs: no-load flows, reduced network loop flows, HVDC impact on flows, reduced link capacities (summer/winter, N-1), equivalent impedances, PST capabilities.

Market Data Split in Zonal Datasets

Market datasets (typically at bidding zone level) must be disaggregated to zonal level for the model.

- **Network-guided disaggregation**: Nodes are assigned to zones based on clustering of the full grid model.
- **Variable-specific allocation**: Data (demand, thermal, RES, etc.) from the market zone is mapped to IoSN zones according to installed capacity from the clustered network, generation characteristics
- **Data quality checks**: Minor adjustments ensure additional considerations, e.g., PECD zones
- **Consistency and coherence**: Aggregated zonal values preserve key properties of the detailed network (number of units, capacities, fuel types).



Q & A

Zonal Modelling & Data Preparation

5. Investment Modelling Framework

Andriy Vovk

Expansion Optimisation: Problem Formulation

Objective: Minimise total system cost under climate uncertainty

CAPEX + FOM

Investment costs and fixed O&M for transmission, offshore cables, converters, and storage

OPEX

Fuel costs, CO_2 costs, variable O&M, start-up costs of generation assets over the modelling horizon

Unserved Energy

Penalties (VoLL) to discourage load curtailment or supply shortages

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min annualized CAPEX, FOM, OPEX, ENS Cost; subject to climate uncertainty
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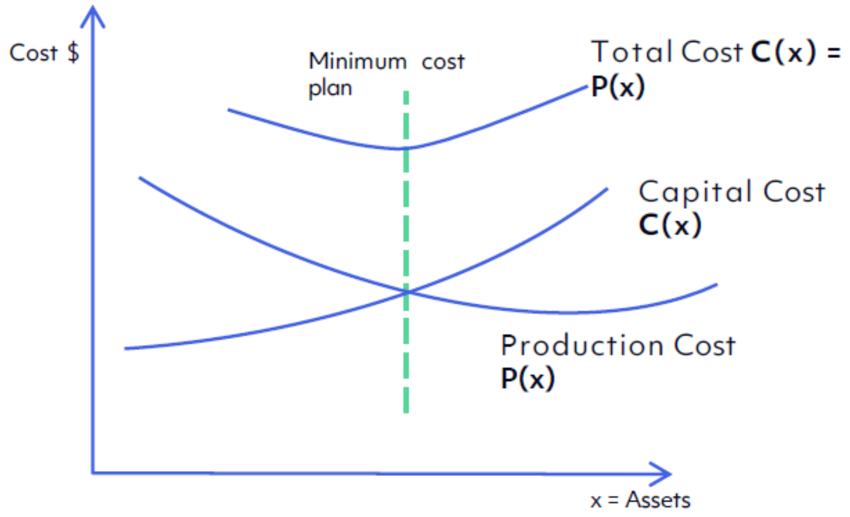
Subject to Constraints

- Power balance at each node and time step
- Network flow constraints (DC load flow / Kirchhoff's laws)
- Capacity bounds on investment candidates (0 ≤ expansion ≤ max)
- Operational limits for generators, storage, and network
- Policy constraints: RES targets, offshore targets, energy efficiency targets



Robust Optimisation – First Ever in TYNDP

Investment decisions are made before weather uncertainty is revealed — solutions must be robust across multiple climate futures.

Key Principle

- The outcomes may be sub-optimum for any specific scenario but should be best across all future uncertainties
- Assessment based on one central scenario with variability on future climate conditions (3 weather scenarios per target years with different weights / probabilities)
- Each target year optimised separately: 2035, 2040, 2050

Weather Scenario Selection (PCA + K-Means)

1. Calculate yearly averages & cumulative anomalies
2. Normalise across all years and models
3. Apply regional weighting (installed RES capacities)
4. PCA dimensionality reduction
5. K-Means clustering (k=3) → 3 representative years

Target	Scenarios (weights)
2035	WS032 (0.24) | WS037 (0.43) | WS059 (0.33)
2040	WS065 (0.20) | WS071 (0.40) | WS077 (0.40)
2050	WS091 (0.23) | WS092 (0.57) | WS106 (0.20)

Optimisation Approach & Target Years

Each target year is assessed separately, starting from the 2035 grid

The starting grid at the borders corresponds to the year 2035. This is the starting point of the expansion optimisation performed for all three target years.

2035

Identify cross-border transmission enhancements that support a more efficient operation of the 2035 scenario system.

2040

Derive cross-border enhancements that help meeting the scenario developments from 2035 towards 2040.

2050

Derive cross-border enhancements that help meeting the scenario developments from 2035 towards 2050.

A multi-step expansion is performed for each target year. All steps use linear programming (LP), where investment candidates are either built fully, partially, or not at all. Following the optimisation steps, a post-expansion analysis filters out borders for which the aggregated expanded capacities are judged too small or unrealistic.

Multi-Step Expansion Process

Three sequential optimisation steps, all using linear programming

Step 1

Real Transmission Candidates

All real onshore and offshore candidates from the transmission investments list

Optimiser selects the optimum combination that minimises total system costs

Linear programming: candidates built fully, partially, or not at all

Partially expanded candidates filtered for reassessment in Step 2

Step 2

Conceptual + Theoretical Candidates

Remaining real candidates + conceptual onshore + theoretical offshore corridors

Properly accounts for investments selected in Step 1

Maximum grid enhancement potentials set through candidates defined

Model freely defines optimum deployment, without exceeding the potential set

Storage Expansion (Integration into the framework in progress)

Only for 2040 and 2050 target years

Linear expansion approach

Maximum trajectories cap expandable capacities per country

Different storage sizes explored (different flexibility types)

Very small or unrealistic values naturally filtered out

Post-processing: model outputs filtered to remove borders with too-small or unrealistic capacity expansions

Step 1: Real Transmission Candidates

All real onshore and offshore candidates from the TYNDP 2026 investment list

All real expansion transmission candidates (both onshore and offshore) from the transmission investments list are fed to the model and the optimiser selects the optimum combination of investment candidates that minimises total system costs.

Input

All real onshore cross-border projects

All real offshore projects (from TYNDP 2026 CBA portfolio)

Each with defined capacity (MW), CAPEX, OPEX, landing points

Output

Optimum combination of candidates selected

Each candidate: fully built, partially built, or not built

Partial builds filtered and passed to Step 2 for reassessment

Linear Programming (LP) Optimisation

Investment variables are continuous: each candidate's expansion lies between 0 and its maximum capacity. The LP minimises total system cost = annualised investment costs + operating costs + unserved energy penalties, subject to power balance, network flow, and operational constraints across all weather scenarios.

Why real candidates first? Real projects have the most detailed cost and technical data, defined landing points, and identified substations. Assessing them first ensures concrete opportunities are prioritised before adding conceptual alternatives in Step 2.

Step 2: Conceptual + Theoretical Candidates

Remaining real candidates, conceptual onshore, and offshore theoretical corridors

All remaining real candidates, conceptual onshore candidates and offshore theoretical corridors candidates are fed to the model, while properly accounting for the selected investment candidates from the first step.

What enters Step 2

- Remaining real candidates not fully selected in Step 1
- Conceptual onshore candidates
- Theoretical offshore corridors (centrally defined by ENTSO-E)
- Step 1 selected investments are locked in

How it works

- Linear programming optimisation (same as Step 1)
- Maximum grid enhancement potentials set through the candidates defined
- Model freely defines the optimum combination of deployment
- Cannot exceed the potential set by the candidate definitions

Top-Down Approach

This step is particularly useful for the top-down approach: maximum grid enhancement potentials are set (through the candidates defined) and the model can freely define the optimum combination of deployment, without exceeding the potential set.

Candidate Types in Step 2

Type	Source	Characteristics
Remaining real	TYNDP 2026 project list	Partially selected or not selected in Step 1; reassessed
Conceptual onshore	TSO-promoters	Cost assumptions defined by TSOs, including costs of internal reinforcements
Theoretical offshore	ENTSO-E (central)	Standardised technology & costs (DEA catalogues); proximity-based

Hydrogen System & Sensitivity Analysis

Co-Optimised Approach (Default)

- H_2 supply dispatch optimised alongside electricity expansion and dispatch – **expansion on electricity only**
- Electrolysers, H_2 storage, and H_2 pipelines modelled explicitly
- H_2 data from TYNDP 2026 Scenario Building Guidelines
- Ensures holistic view of cross-sector infrastructure needs

Frozen H_2 Sensitivity

- H_2 dispatch frozen (fixed to the outcomes of the relevant scenario)
- Only electricity system is optimised
- Purpose: isolate benefits from electrical system optimisation only
- Helps appraise what share of benefits comes from electricity vs. H_2 system flexibility

Note: H_2 system granularity in line with Scenario Building exercise (no zonal modelling for hydrogen).

Q & A

Investment Modelling Framework

6. Consideration of Internal Constraints

Mathilde Ceripa

Internal Constraints Consideration

Method 1: Expansion without Internal Constraints

- Expansion with only cross-border capacities activated (no internal constraints activated)
- After expansion : Dispatch simulations with/without IoSN portfolio --> allows us to assess costs from internal constraints as a post process
- Advantage: associates a cost with internal constraints generated by new interconnections
- Advantage: emphasises that internal networks must develop in parallel with interconnections
- Limitation: does not show projects no longer profitable due to internal constraints

Method 2: Expansion with Internal Constraints

- Expansion with internal capacities activated alongside cross-border capacities
- Advantage: shows the impact of internal networks on the choice of optimal expansion portfolio
- Limitation: optimiser can bypass congestion by investing in interconnections, complicating interpretation – fixed by having portfolio of candidates capped by IoSN results of Method 1
- In TYNDP 2026, network/market horizons do match for short-term (2035), ensuring consistency

Method 1 is the primary approach and Method 2 provides additional insight. Both methods can be complementary.

These methods do not aim at identifying internal reinforcement needs. They rather evaluate the mutual impact between internal constraints and cross-border developments.

Q & A

Internal Constraints

7. Conclusion and Next Steps

Franck Dia Wagoum

Key Takeaways

Pan-European Expansion Optimisation	LP-based optimisation minimises total system cost through expansion on the electricity transmission system.
Robust Under Climate Uncertainty	3 representative weather scenarios per target year via PCA and K-Means from PECD v4.2.
Enhanced Spatial Representation	Zonal model with ~102 zones capturing physical flows through Kirchhoff's laws.
Multi-Sector Integration	Explicit hydrogen system modelling with co-optimised dispatch.
Multi-Step Investment Process	Real candidates first, then conceptual/theoretical, including storages expansion.
Internal Constraints Assessed	Complementary methods to evaluate impact of internal network limitations.

Next Steps & Public Consultation

- This methodology is open for public consultation
- Your feedback is essential to ensure transparency and stakeholder buy-in
- Submit your comments through the ENTSO-E consultation platform

Public Consultation ends on 3 April 2026

consultations.entsoe.eu

Deliverables

- TYNDP 2026 Infrastructure Gaps Report: system needs results + infrastructure gaps
- ONDP 2026 reports: offshore system focus, mapping offshore corridors with costs and distances
- IoSN Methodology Final Report: full documentation of assumptions, data inputs, and modelling framework

TYNDP 2026 Key Milestones

WE ARE HERE

Q1 2026

TYNDP 2026 draft IoSN Methodology report

Public consultation
& stakeholder webinar

Q2 2026

TYNDP 2026 Scenarios Report

Including publication of scenario
assumptions & datasets

Q4 2026 – early 2027

TYNDP 2026 Cost-Benefit Analyses

Delivery of project-level
CBA assessments

TYNDP 2026 Infrastructure Gaps and ONDP Reports

System needs results
& infrastructure gaps

Thank You

Your feedback is valuable to strengthen this methodology.

Public consultation: consultations.entsoe.eu

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